



Atmospheric stability and its influence on wind turbine loads

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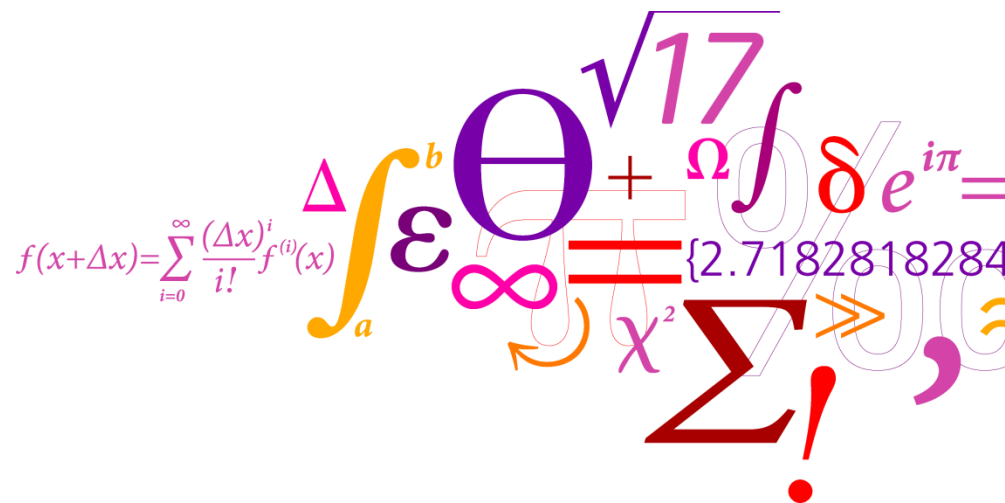
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Influence of atmospheric stability on wind turbine loads

Ameya Sathe, Jakob Mann, Thanasis Barlas,
Wim Bierbooms, Gerard van Bussel

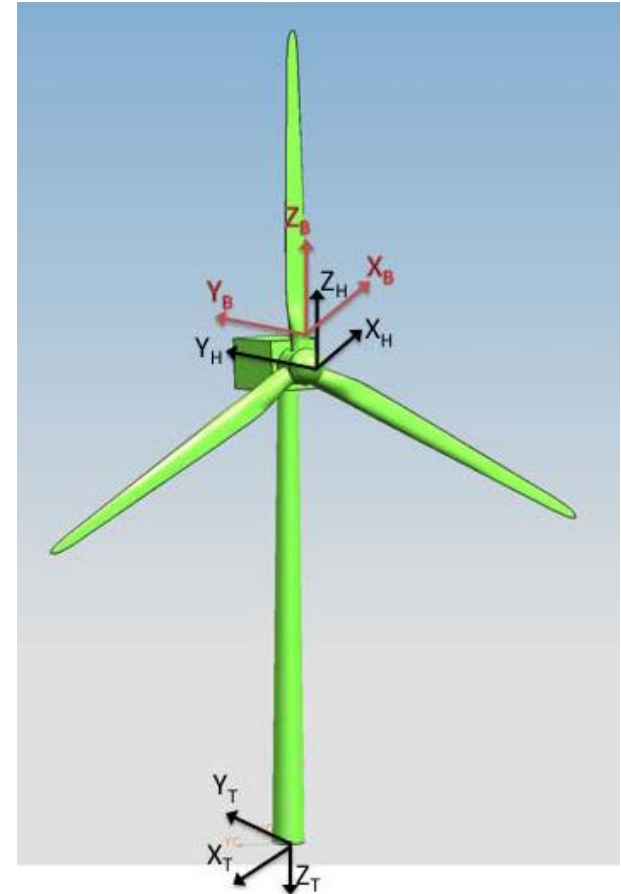


What loads are being investigated?

- Blade root flapwise and edgewise loads
- Tower foreaft loads
- Rotor M_x , M_y and M_z loads

What inputs depend on atmospheric stability?

- Wind Profiles
- Atmospheric turbulence (free stream conditions)



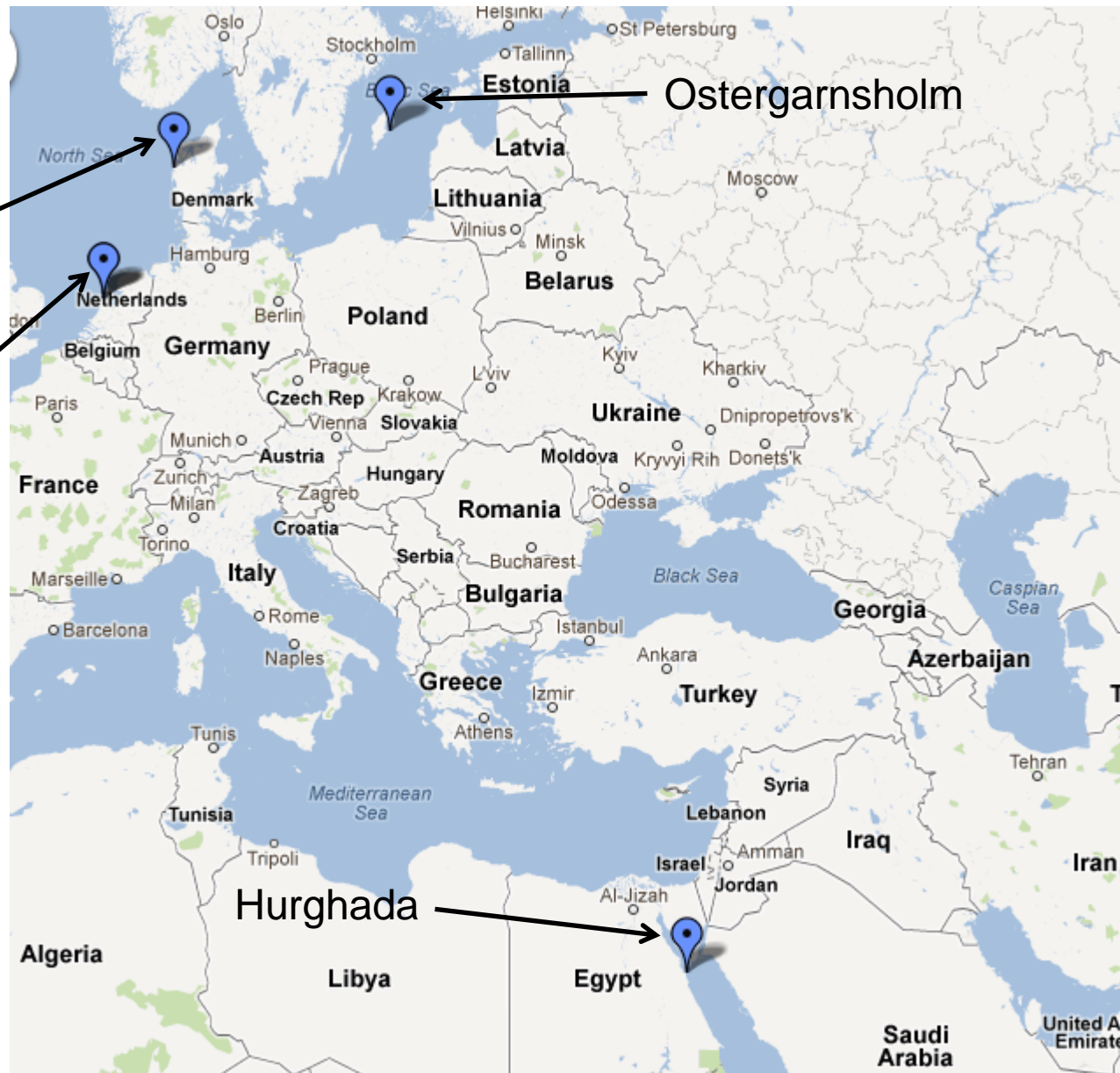
Outline

- Sites
- Wind speed and stability histograms
- Wind profiles
- Turbulence
- Simulation environment
- Load Cases
- Results of load calculations
- Conclusions

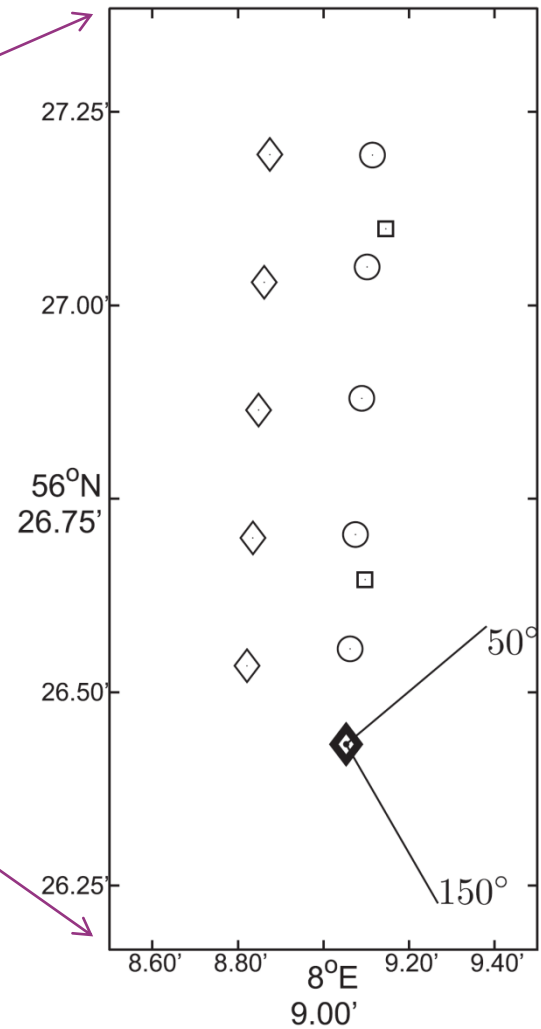
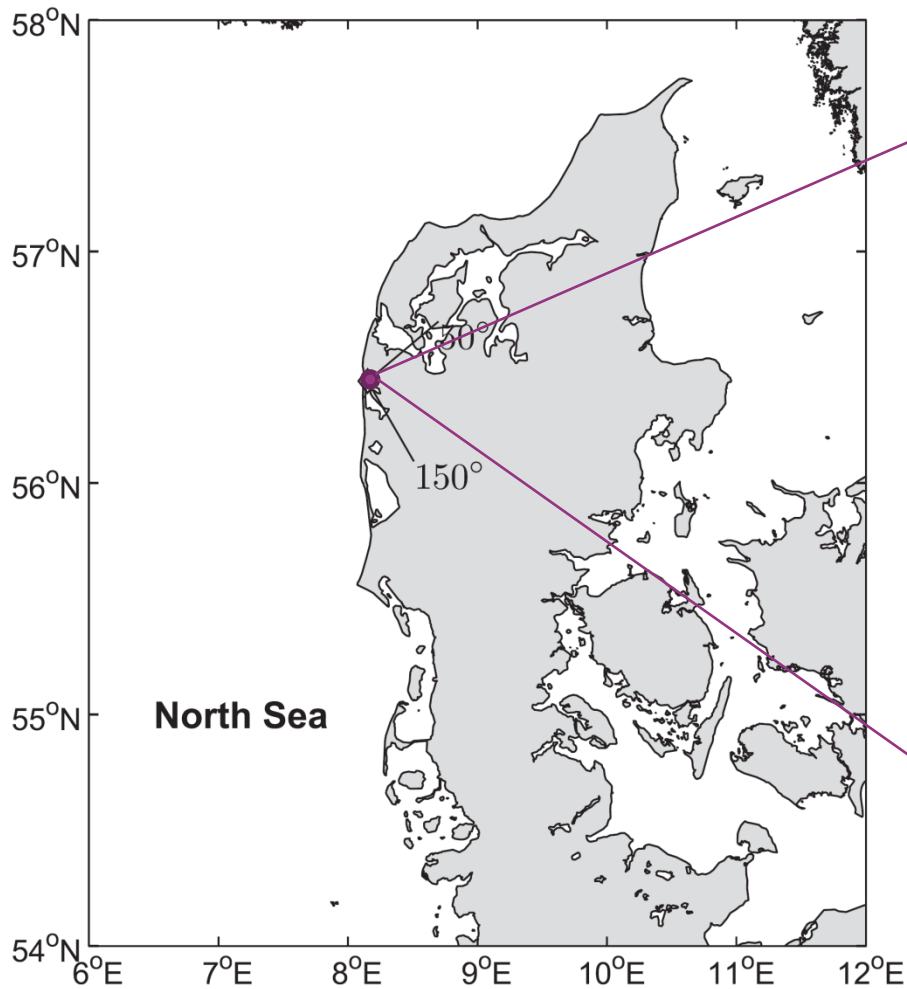
Sites

Høvsøre

Egmond aan Zee



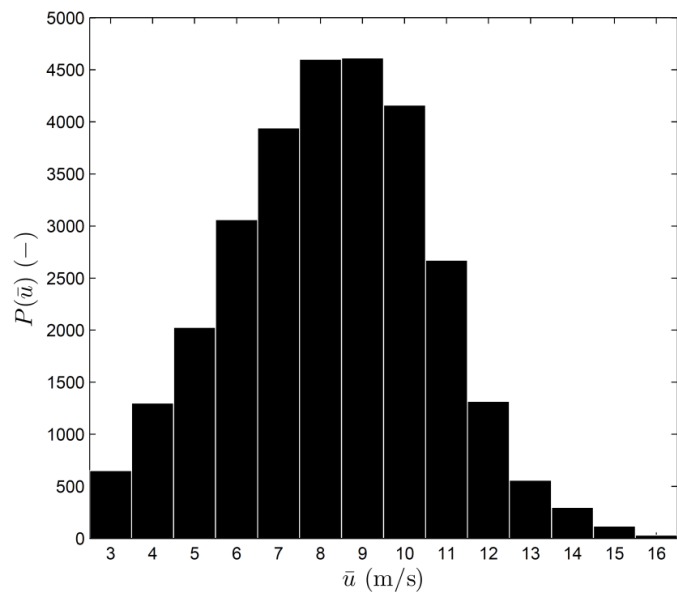
Høvsøre



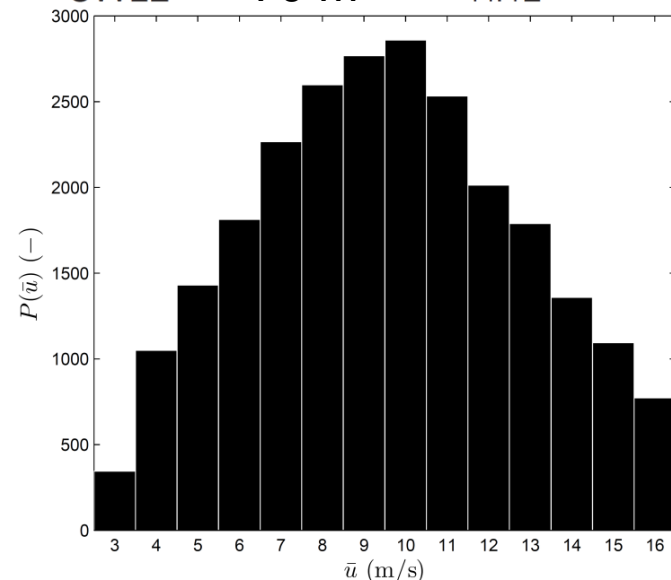
Histograms of mean wind speeds



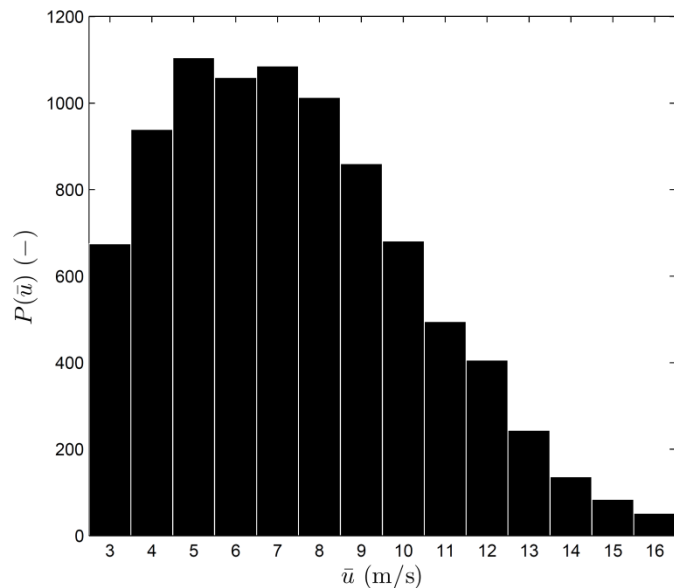
Høvsøre 90 m 9.13 3.82



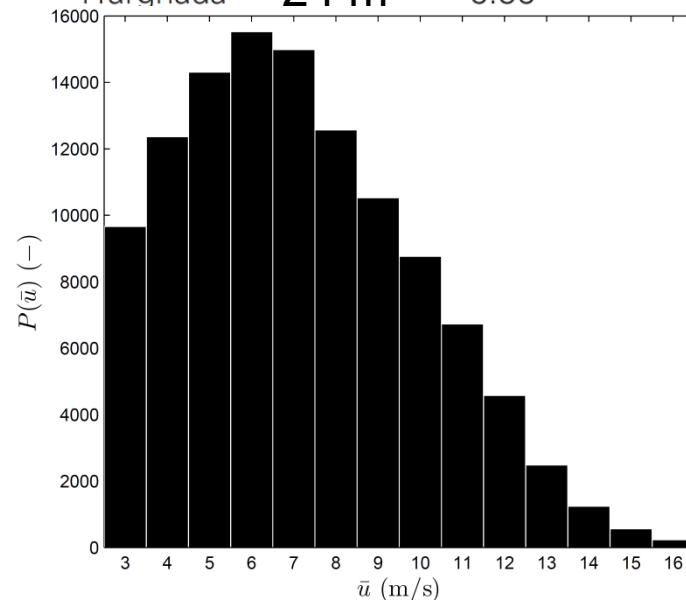
OWEZ 70 m 11.12 3.07



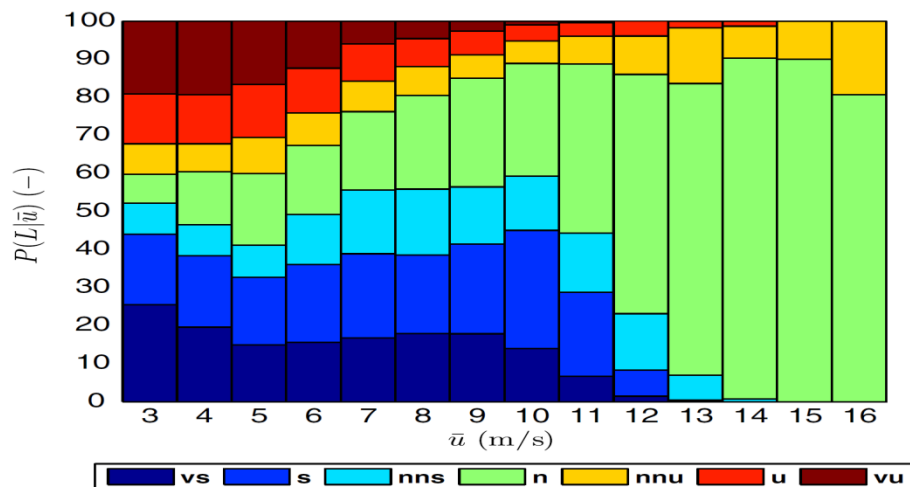
Östergarnsholm 30 m 7.86 2.18



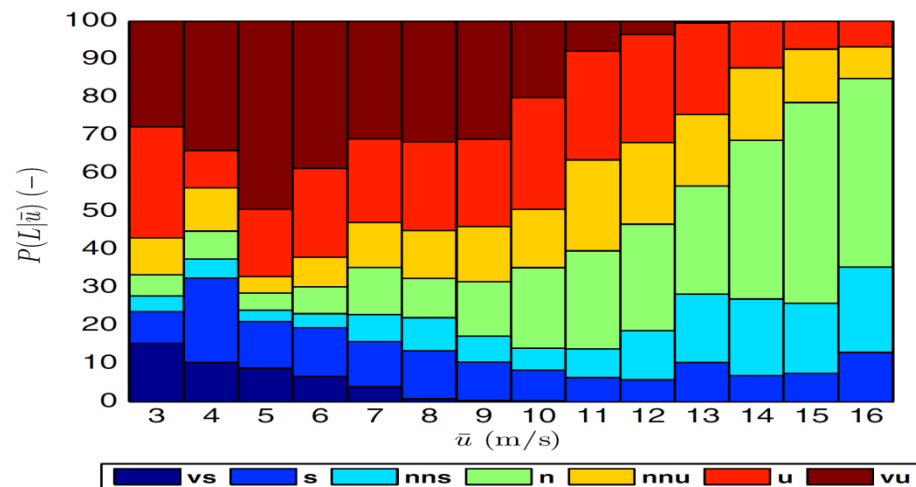
Hurghada 24 m 6.56 2.70



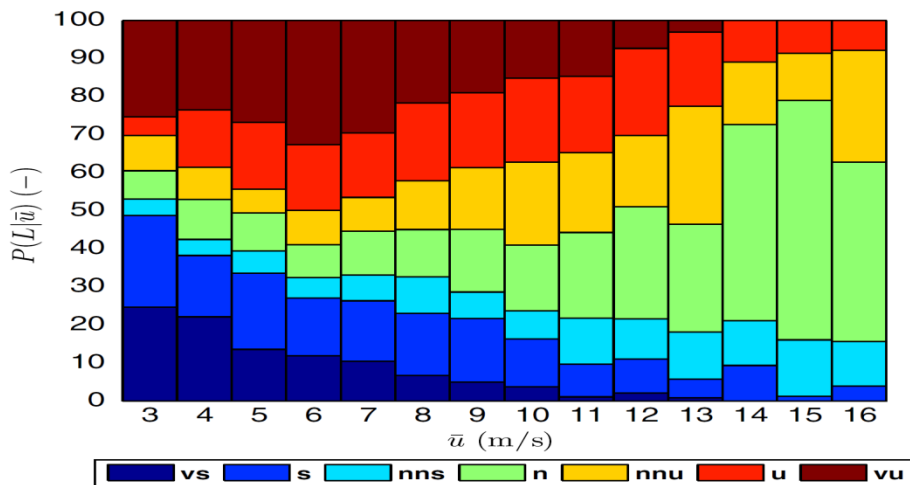
Stability Histograms



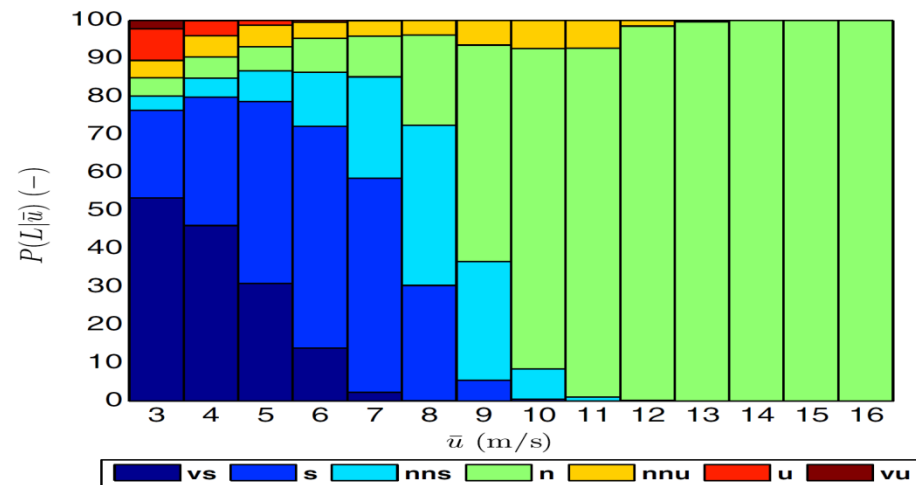
(a) Høvsøre



(b) OWEZ



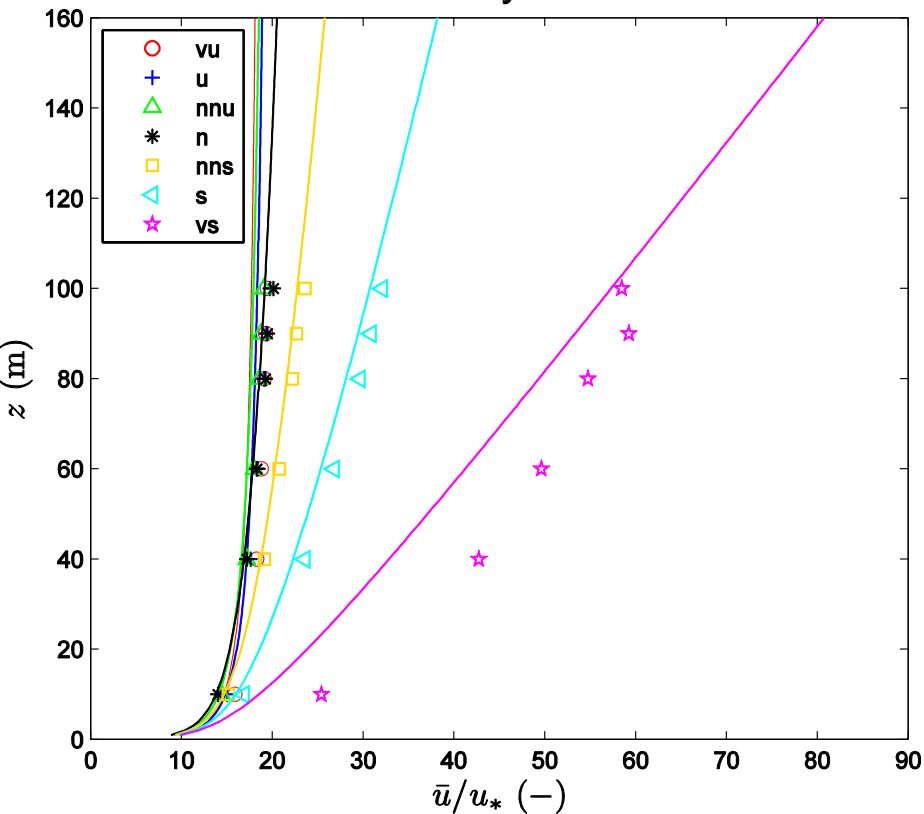
(c) Östergarnsholm



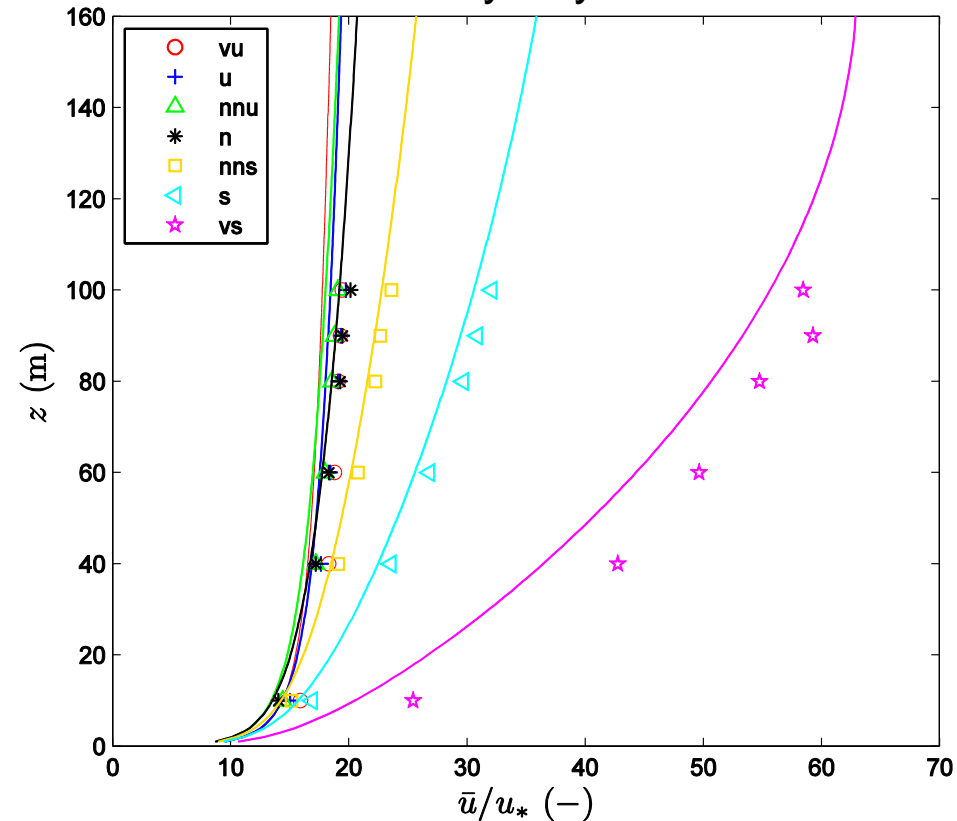
(d) Hurghada

Wind Profile Analysis - Høvsøre

Surface Layer Model

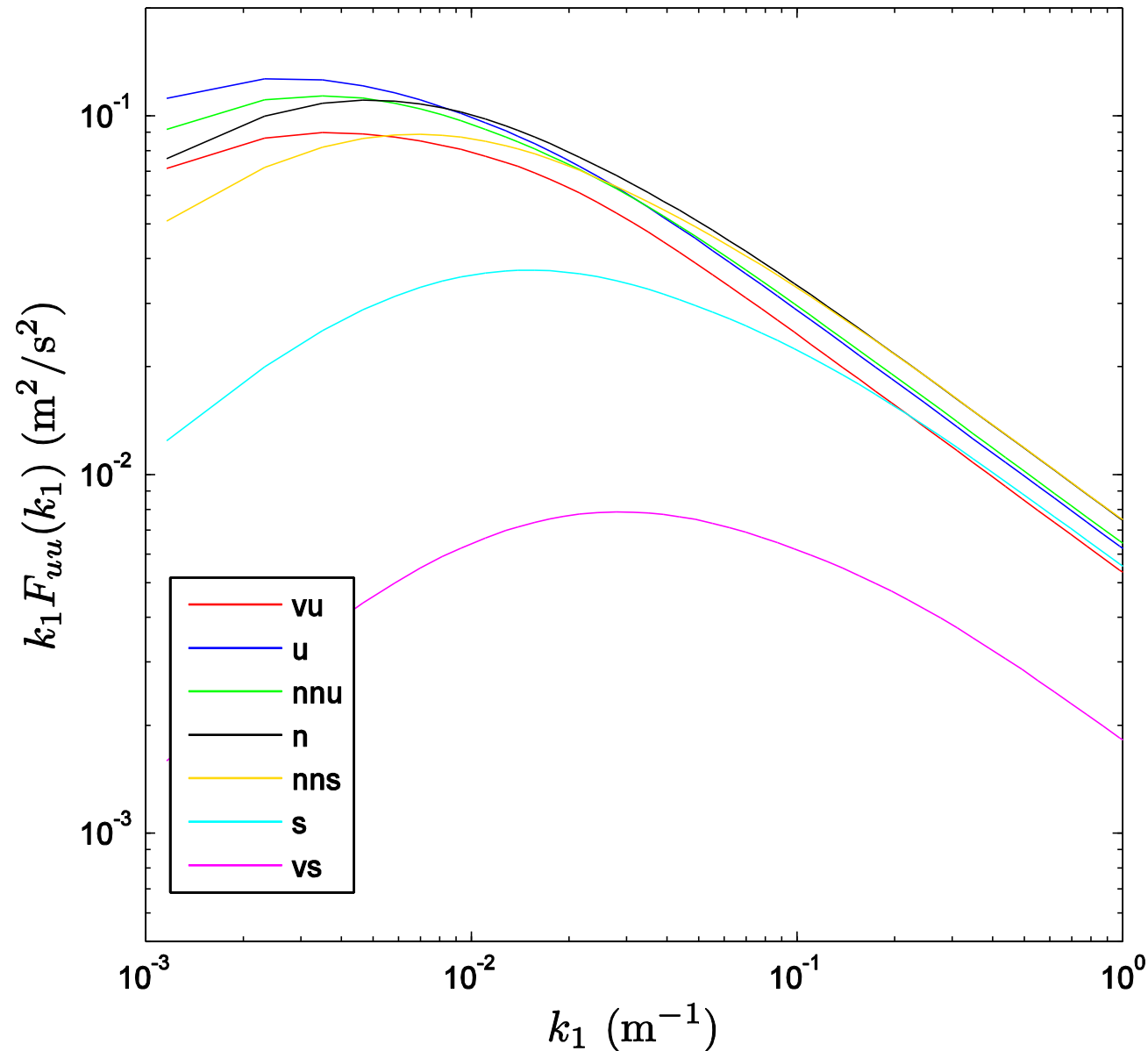


Boundary Layer Model



Sathe A, Gryning SE, Peña A. Comparison of the atmospheric stability and wind profiles at two wind farm sites over a long marine fetch in the North Sea. *Wind Energy* 2011; **14**(6): 767–780. DOI: 10.1002/we.456.

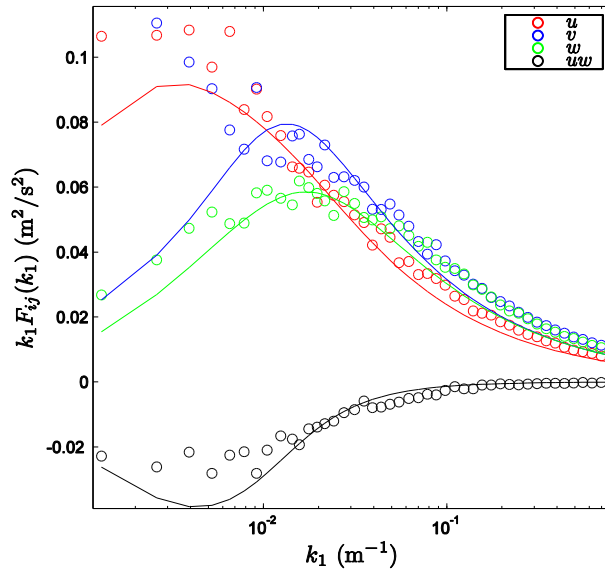
Turbulence Spectra



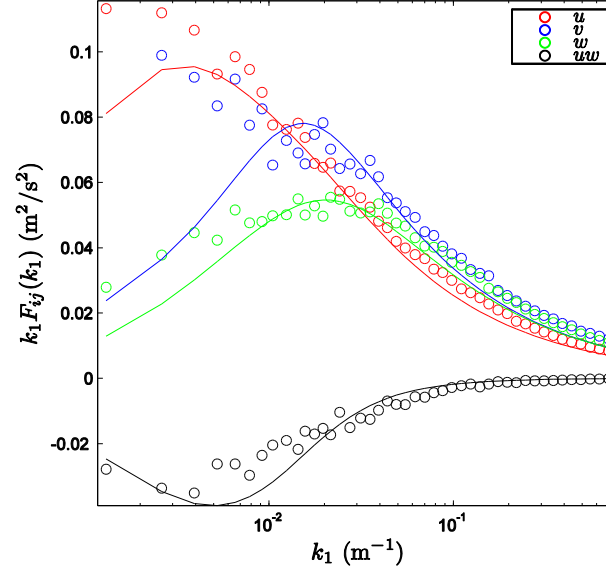
Turbulence Spectra



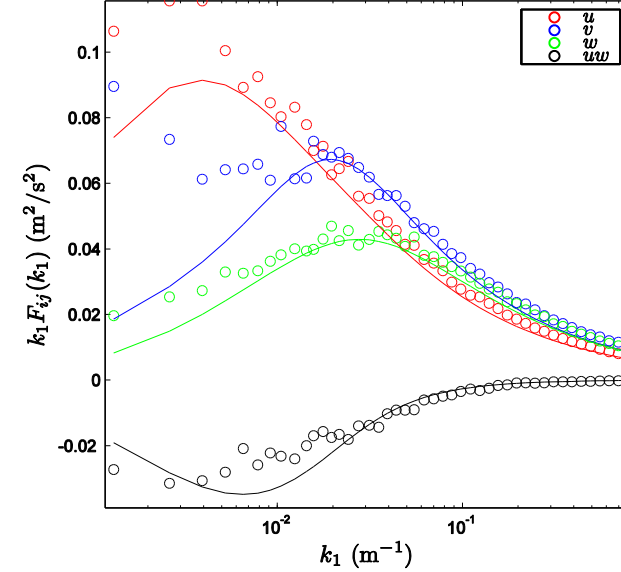
Very unstable



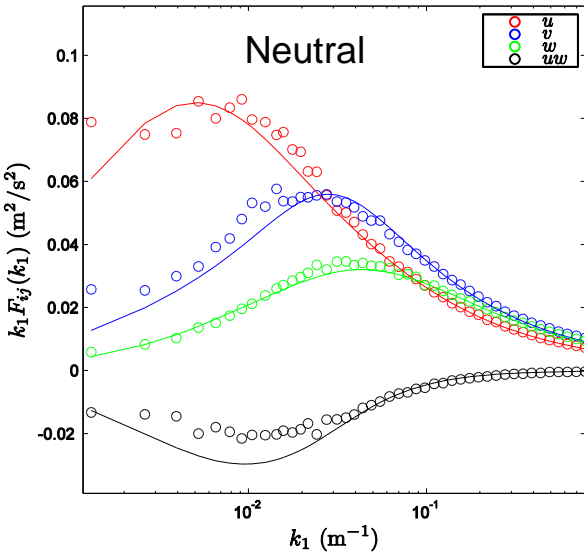
Unstable



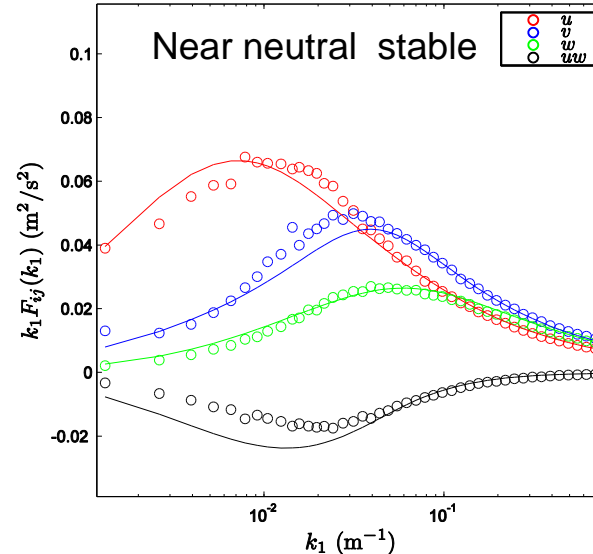
Near neutral unstable



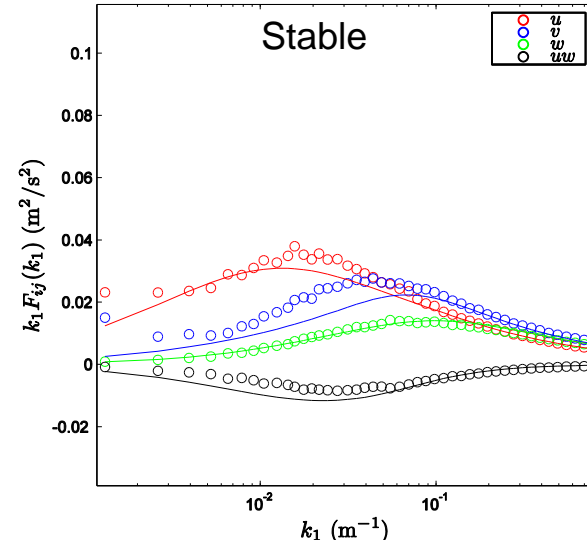
Neutral



Near neutral stable



Stable



Simulation Environment

NREL 5 MW wind turbine

HAWC 2 code

Wind speed bins: 3 – 16 m/s

Maximum power	5 MW
Number of blades	3
Rotor diameter	126 m
Hub height	90 m
Cut-in wind speed	3 m s^{-1}
Rated wind speed	11.4 m s^{-1}
Cut-out wind speed	25 m s^{-1}
Control	Variable speed, collective pitch

Load Cases

$$D = \sum D_i^m N_i = D_{\text{EQ}}^m N_{\text{EQ}}$$

$$D_{\text{EQ}} = \left(\frac{\sum D_i^m N_i}{N_{\text{EQ}}} \right)^{1/m}$$

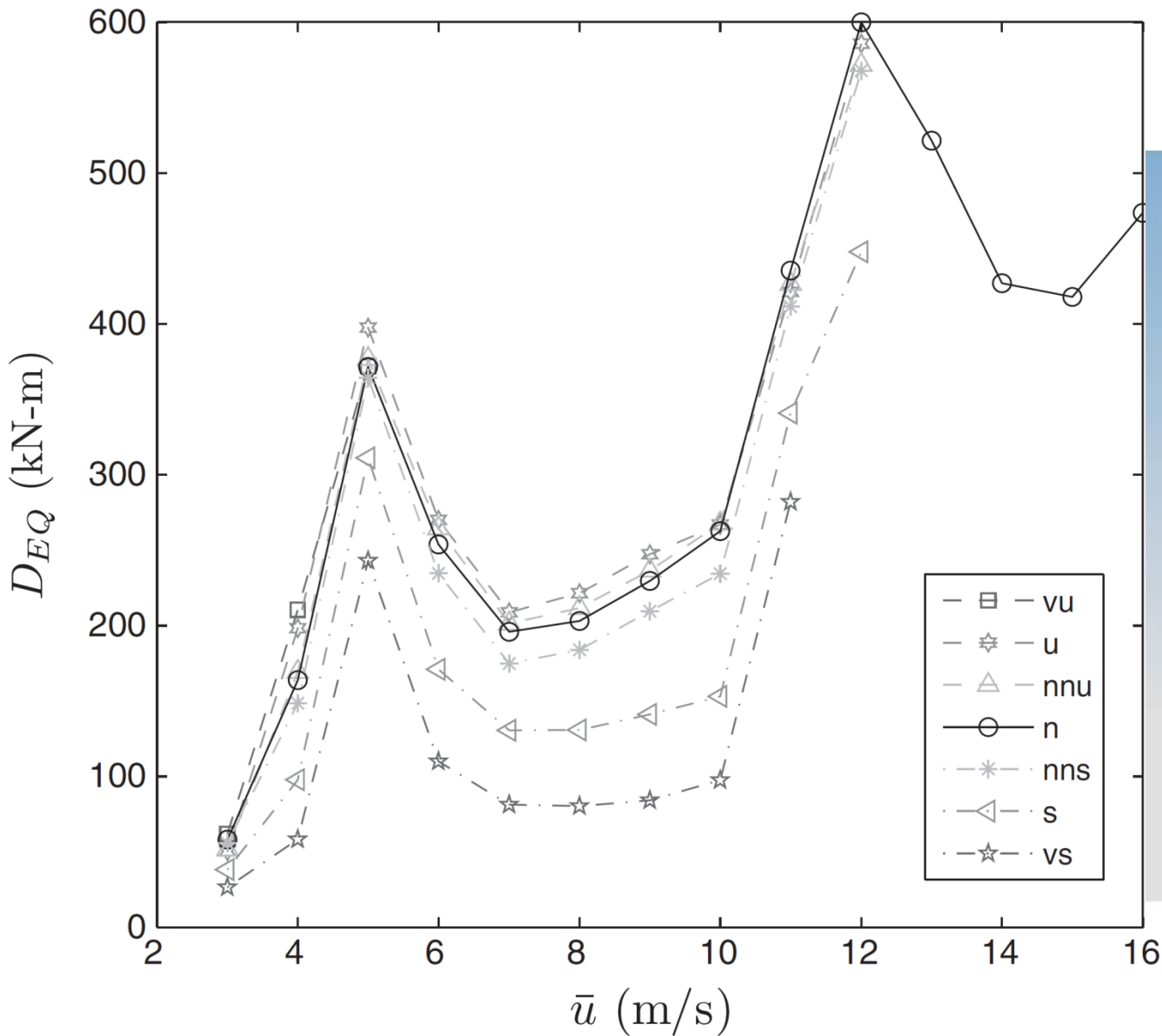
$$D_{\text{EQC}} = \sum_{\bar{u}=3}^{16} \left(\sum_{L=\text{vu}}^{\text{vs}} D_{\text{EQ}} \times P(L|\bar{u}) \right) \times P(\bar{u})$$

Table IV. Load cases.

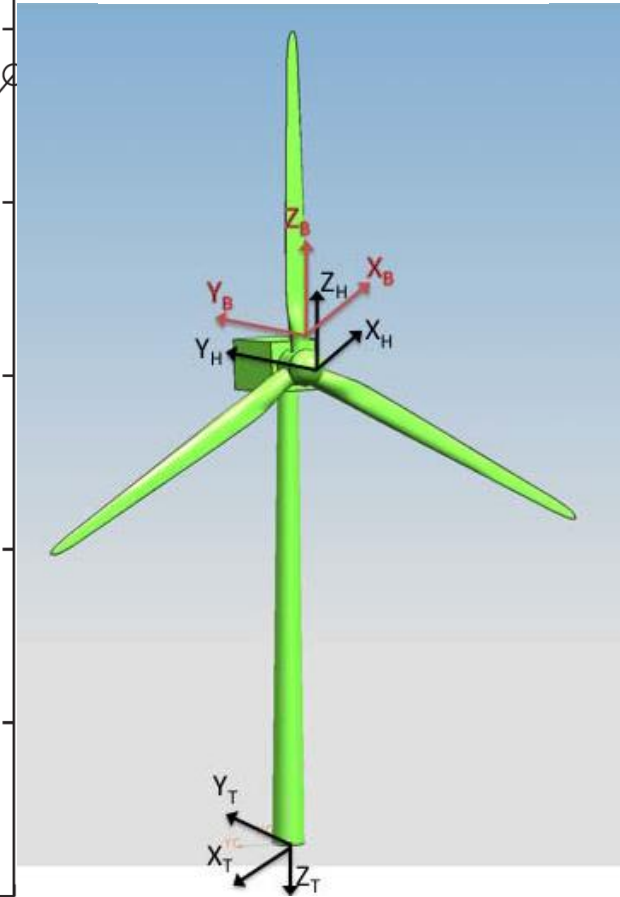
Cases

I	Diabatic boundary-layer wind profile and turbulence
II	Neutral boundary-layer wind profile and turbulence
III	Diabatic surface-layer wind profile and turbulence
IV	IEC load case, power law exponent = 0.2

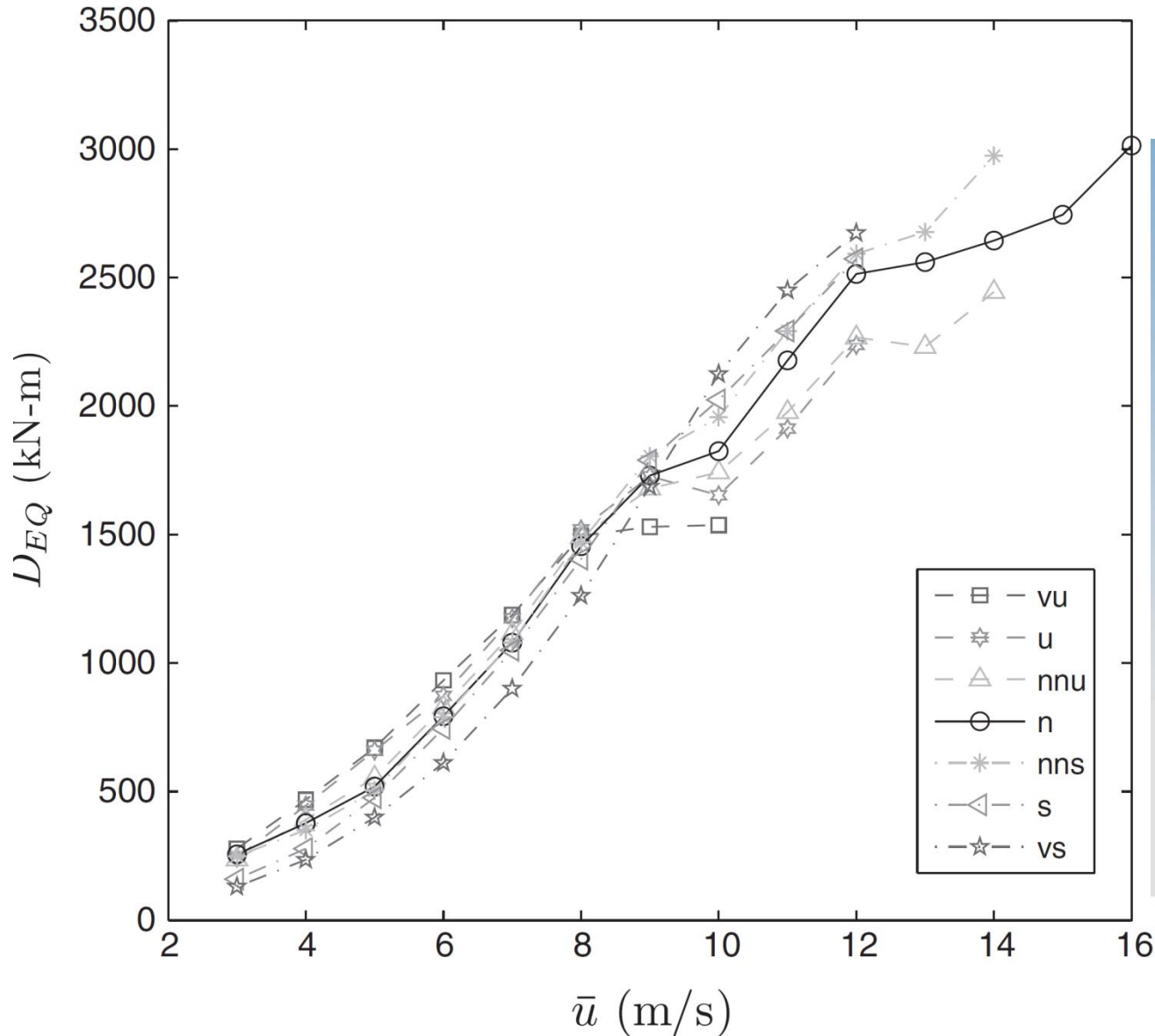
Tower base fore-aft bending moment



$$D_{EQ} = \left(\frac{\sum D_i^m N_i}{N_{EQ}} \right)^{1/m}$$

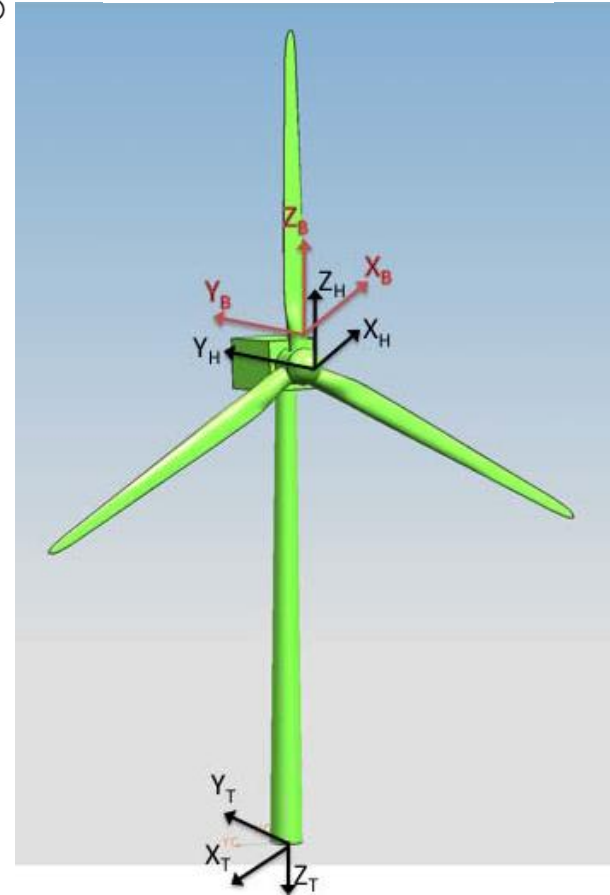


Blade root flapwise bending moment

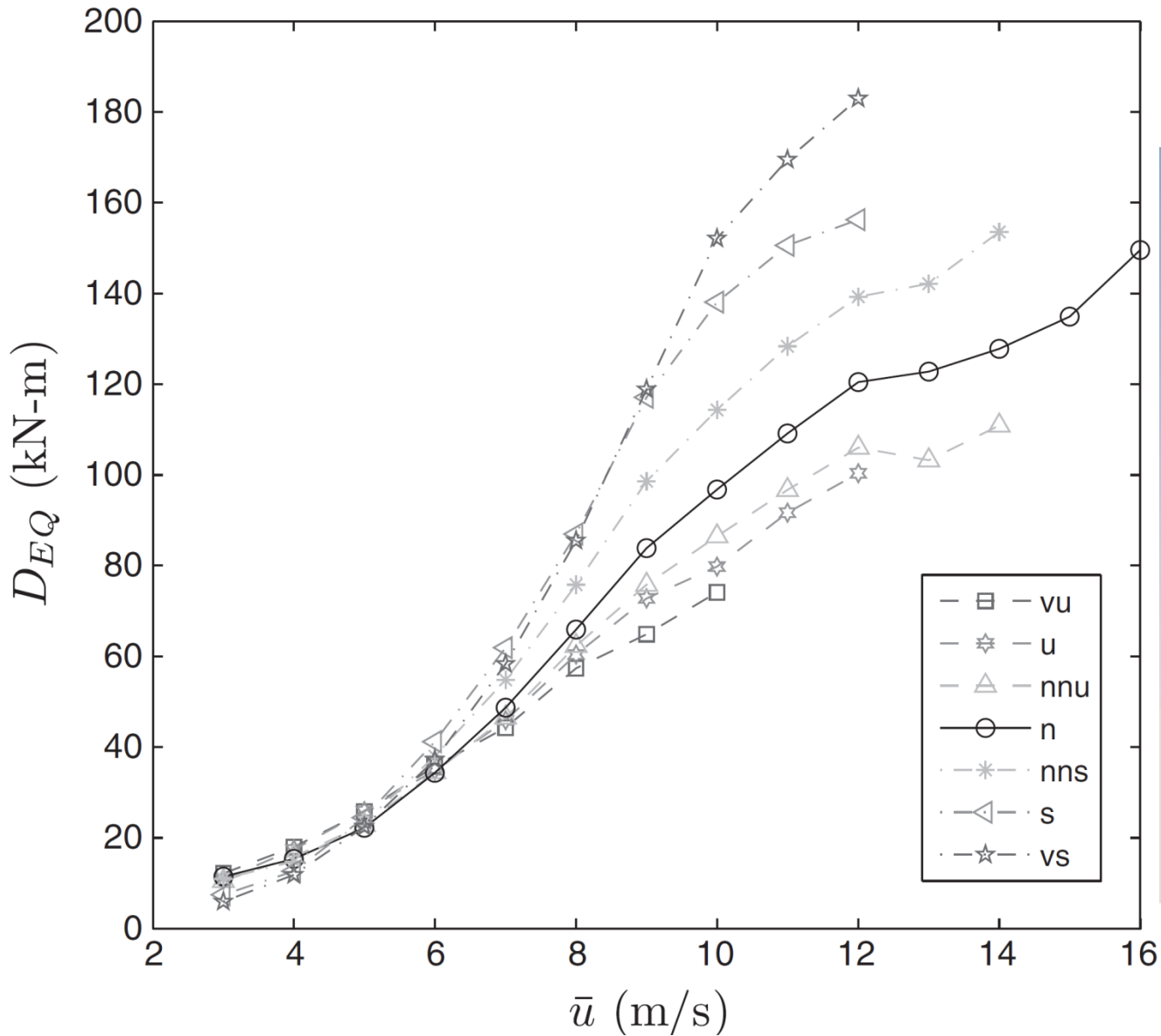


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$$D_{EQ} = \left(\frac{\sum D_i^m N_i}{N_{EQ}} \right)^{1/m}$$

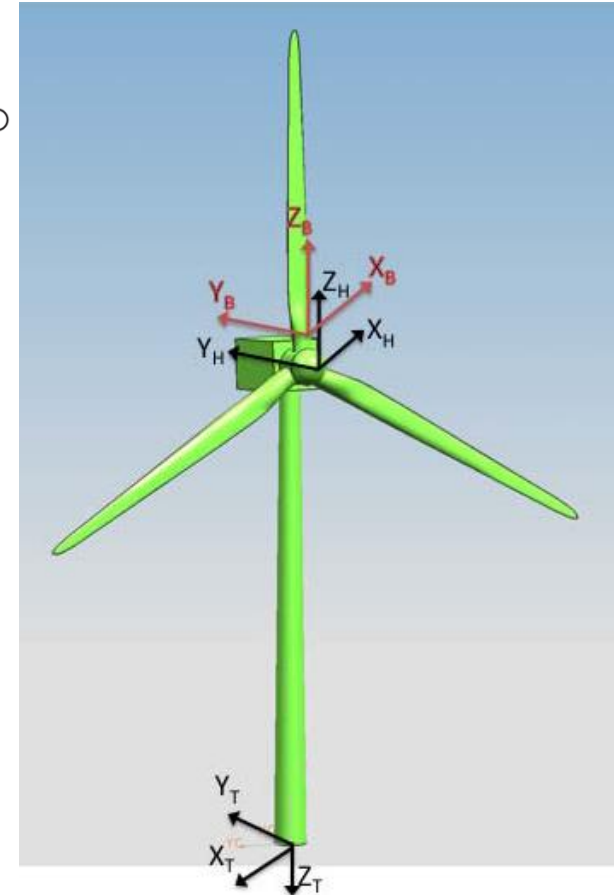


Rotor Mx bending moment



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$$D_{EQ} = \left(\frac{\sum D_i^m N_i}{N_{EQ}} \right)^{1/m}$$



Cumulative Damage Equivalent Load

$$D_{EQC} = \sum_{\bar{u}=3}^{16} \left(\sum_{L=vu}^{vs} D_{EQ} \times P(L|\bar{u}) \right) \times P(\bar{u})$$

Table V. Normalized D_{EQC} of bending moments at different sites.

	Blade root		Tower base	Rotor loads	
Cases					
Høvsøre					
I					
II					
III					
IV					

Table IV. Load cases.

Cases	
I	Diabatic boundary-layer wind profile and turbulence
II	Neutral boundary-layer wind profile and turbulence
III	Diabatic surface-layer wind profile and turbulence
IV	IEC load case, power law exponent = 0.2

Conclusions

- The influence of atmospheric stability on loads can be considered significant (up to 17 %) depending on the component of interest
- The influence of using different wind profile models is up to a limited extent (up to 7 %), and depends on the component of interest.

Open questions

- Should atmospheric stability be included in load calculations?
- Are the differences in the calculated loads larger than the uncertainties in the load calculations?

Thank you!

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